Green Networking: Downlink Considerations

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Eitan Altman†, Cengis Hasan‡, Jean-Marie Gorce‡, Laurent Roullet§

†INRIA, 2004 Route des Lucioles, 06902 Sophia-Antipolis Cedex, France
†University of Lyon, INRIA, INSA-Lyon, CITI Laboratory, F-69621, France
§Alcatel-Lucent Bell Labs Villarceaux Route de Villejust 91620 Nozay, France
eitan.altman@inria.fr, cengis.hasan@inria.fr, jean-marie.gorce@insa-lyon.fr, laurent.roullet@alcatel-lucent.com

***Abstract*—In this work, we consider downlink transmission in cellular networks where we target to reduce the energy consumption by switching off some base stations by such a way that the distribution of SINR remains unchanged. This is a mean of green networking in cellular networks in downlink consideration. This paper analyzes for line and plane cases, the gain in power consumption obtained after switching off base stations. By computations we observe that the more the operational cost the more the gain in power consumption.**

I. Introduction

Green networking is the practice of selecting energy-efficient networking technologies and products, and minimizing resource use whenever possible [1].

Green networking covers all aspects of the network (personal computers, peripherals, switches, routers, and communication media). Energy efficiencies of all network components must be optimized to have a significant impact on the overall energy consumption by these components. Consequently, these efficiencies gained by having a "green network" will reduce CO_2 emissions and thus will help mitigate global warming [2].

With a growing awareness to the dangers related to large scale energy consumption and drafting of many international agreements as well as legislation have reduced energy consumption in several sectors [3]. There is also a growing willingness to reduce energy consumption in wireless networks. In this work, we consider downlink transmission in cellular networks where we target to reduce the energy consumption by switching off some BSs by such a way that the distribution of SINR remains unchanged. We assume full frequency reuse. Each mobile is associated with the BS being nearest to it. All BSs being out the nearest one cause interference to the mobile. The question that we ask is "How many BSs can be switched off in order that the distribution of the SINR remains unchanged?". We model the problem as a homogenous independently marked Poisson point process.

We analyze for line and plane cases, the gain in power consumption obtained after switching off BSs. It turns out from calculations that the more the operational cost the less the gain in power consumption, and similarly, the higher the dimension (distribution of BSs in line and plane means one and two dimensions, respectively) the less the gain in power consumption.

II. Point Processes Preliminaries

Stochastic geometry is a rich branch of applied probability which allows the study of random phenomena on the plane or in higher dimensions. It is intrinsically related to the theory of point processes [4]. A point process (p.p.) Φ can be depicted as a *random collection of points* in space. More formally, Φ is a random, finite or countably-infinite collection of points in the space $\mathbb{R}_d$, without accumulation points [5]. A point measure is a measure which is locally finite and which takes only integer values on some space E. Each such measure can be represented as a discrete sum of Dirac measures on E

$$\Phi = \sum_i \delta_{X_i}. \tag{1}$$

The random variables $\{X_i\}$ taking values in E are the points of Φ. The *intensity measure* Λ of Φ on B is defined as $\Lambda(B) = \mathbb{E}\Phi(B)$ denoting the expected number of points in $\Phi \cap B$. For some $\mathrm{d}x$, if $\Lambda(\mathrm{d}x) = \lambda \mathrm{d}x$ is multiple of Lebesgue measure, we call Φ a *homogeneous p.p.* and λ is its intensity parameter [5].

A. Poisson point processes

A p.p. on some metric space E with intensity measure Λ is Poisson if for all disjoint subsets $A_1, \dots, A_n$ on E, the random variables $\Phi(A_i)$ are independent and Poisson.

B. Marked point processes

In a marked point process (m.p.p.), a mark belonging to some measurable space and carrying some information is attached to each point. In our context, the points are the BSs and the marks are considered to be the transmitted power by each BS.

III. The model

We consider a homogenous independently marked Poisson point process (i.m.P.p.p.) of base stations. Assume that each of these BSs transmits with power P. We show by Φ the i.m.P.p.p with intensity measure $\tilde{\lambda} = \lambda P$.

Consider a mobile at an arbitrary point on the plane, say the origin. Let p_0 denote the point in Φ which is the closest to it, represents the BS to which it is connected. Let $|x_i|$ be the distance of p_i to the origin. We assume attenuation due to a path-loss. The power of the transmission received from p_0

is thus given by $P|x_0|^{-\alpha}$. The total interference from other BSs is $\sum_{i>0}|x_i|^{-\alpha}$. Thus the SINR at the mobile is

$$\text{SINR} = \frac{P|x_0|^{-\alpha}}{P\sum_{i>0}|x_i|^{-\alpha} + \sigma^2} \tag{2}$$

where α and σ^2 stand for path loss and additive noise variance, respectively.

IV. Switching off Base Stations

Choose some $0 < q < 1$. Let Φ^q denote the homogenous i.m.P.p.p. obtained from the original one by deleting independently points with probability $1-q$. Deleted points correspond to BSs that are switched off. The intensity measure of Φ^q is $\tilde{\lambda}_q = \lambda qP$. This is called the thinning property of the Poisson p.p. [5].

Define $w(q) = q$ when considering the problem on the line, and $w(q) = \sqrt{q}$ on the plane [5]. Now, the point process $\{y_i\}$ where $y_i = x_i/w(q)$ is obviously a homogenous i.m.P.p.p with parameter λq. Therefore, if we replace all x_i in (2) by y_i and replace P by P' then we can interpret the SINR that is obtained as one corresponding to a network where BSs are located according to a homogenous i.m.P.p.p with intensity λqP, BSs are the switched off with probability $1-q$ independently, and the power of each BS is increased replaced by P'.

Now if we choose $P' = Pw(q)^{-\alpha}$ then the SINR is seen to remain unchanged.

We conclude that if BSs are switched off with probability $1-q$ then the transmission power of the base station has to increase by $(w(q))^{-\alpha}$ in order for the distribution of the SINR to remain unchanged.

V. Optimal switching off probabilities

Assume that the power used by a base station that transmits at a power P is given by $P_0 + \beta P$. We consider some operational costs which arise from overhead assumed to be constant. Here, the power consumed due to operational costs is represented by P_0. We also suppose that $\beta \geq 1$. Then the power consumption density of the original network is $\lambda(P_0 + \beta P)$.

A. The line

We are interested to see what is the gain in energy by switching off BSs (independently) with probability $(1-q)$, given that at the same time we increase the transmission energy to compensate for decreasing the resources in a way that the probability distribution of the SINR are unchanged.

After switching off base stations, the power consumption density of the network is

$$\lambda q(P_0 + \beta P') = \lambda q(P_0 + \beta P q^{-\alpha}). \tag{3}$$

So that the gain in power consumption density is

$$\begin{aligned} G(q) &= \lambda(P_0 + \beta P) - \lambda q(P_0 + \beta P') \\ &= \lambda(P_0(1-q) + \beta P[1 - q^{1-\alpha}]). \end{aligned} \tag{4}$$

The switching probabilities that maximize this gain are obtained by solving

$$\frac{dG(q)}{dq} = -P_0 - (1-\alpha)\beta P q^{-\alpha} = 0 \tag{5}$$

which gives

$$1 - q^* = 1 - \left(\frac{\beta P(\alpha-1)}{P_0}\right)^{\frac{1}{\alpha}}. \tag{6}$$

B. The plane

We calculate by the same way the power consumption density of the network after switching off BSs

$$\lambda q(P_0 + \beta P') = \lambda q(P_0 + \beta P q^{-\alpha/2}). \tag{7}$$

The gain in power consumption density is given by

$$\begin{aligned} G(q) &= \lambda(P_0 + \beta P) - \lambda q(P_0 + \beta P') \\ &= \lambda(P_0(1-q) + \beta P[1 - q^{1-\alpha/2}]). \end{aligned} \tag{8}$$

The switching probabilities that maximize this gain are obtained by solving

$$\frac{dG(q)}{dq} = -P_0 - \beta P(1-\alpha/2)q^{-(\alpha/2)} = 0 \tag{9}$$

$$\frac{dG(q)}{dq} = -P_0 - \beta P(1-\alpha/2)q^{-(\alpha/2)} = 0 \tag{10}$$

which gives

$$1 - q^* = 1 - \left(\frac{\beta P(\alpha/2-1)}{P_0}\right)^{\frac{1}{\alpha/2}}. \tag{11}$$

VI. Simulation Results

In this section, we compare the optimal switching off probabilities with respect to path loss α for different operational costs P_0, and we also match the optimal switching off probabilities in terms of β for some α. Moreover, gain in power consumption is compared with respect to α for different P_0.

In Figure 1 and 2, we depict the change of switching off probabilities in terms of path loss α. From figures, we observe that for higher path loss values, the number of switched off BSs is decreased. In other words, we need to keep more BSs switched on. Also, for the same path loss value optimum switching off probability is higher for higher P_0. That means, the switching off strategy tells us to remove base stations with a higher probability for higher P_0. On the other hand, if we compare the optimal switching off probabilities with respect to the dimension (line or plane), we remark that it is necessary to switch on more BSs.

We depict in Figure 3 and 4 the comparison of switching off probabilities in terms of β for $\alpha = (2.5, 4, 6)$. We interpret that for higher values of β the number of switched on BSs is increased. Furthermore, in case of plane the used switched on BSs is higher than that of line.

In Figure 5 and 6, the comparison of gain in power consumption $G(q^*)$ with respect to α is given. We calculate $G(q^*)$ in terms of optimal switching off probabilities. It is assumed to be unit intensity parameter λ. We observe that as long as P_0 increases, the obtained $G(q^*)$ increases. This means that for high operational costs the gain in power consumption by switching off BSs is also high.

VII. Acknowledgement

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References

[1] http://searchnetworking.techtarget.com/

[2] N. Chilamkurti, S. Zeadally, and F. Mentiplay, "Green networking for major components of information communication technology systems," *EURASIP Journal onWireless Communications and Networking*, vol. 2009.

[3] E. Altman, M. K. Hanawal, R. El-Azouzi, and S. Shamai, "Tradeoffs in green cellular networks," GreenMetrics Workshop, held in conjunction with SIGMETRICS, San Jose, USA, June 2011.

[4] M. Haenggi, J. G. Andrews, F. Baccelli, O. Dousse, and M. Franceschetti, "Stochastic geometry and random graphs for the analysis and design of wireless networks," *IEEE Journal on Selected Areas in Communications*, vol. 27, pp. 1029–1046, Sept. 2009.

[5] François Baccelli, and Bartłomiej Błaszczyszyn. "Stochastic geometry and wireless networks: volume I theory", *Foundations and Trends in Networking*, vol. 3, pp. 249–449, 2009.

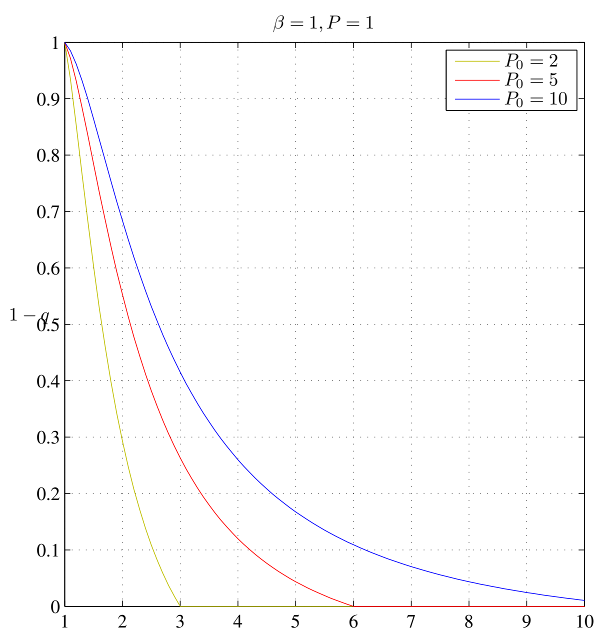

Fig. 1. The change of optimal switching off probabilities with respect to path loss in case of line

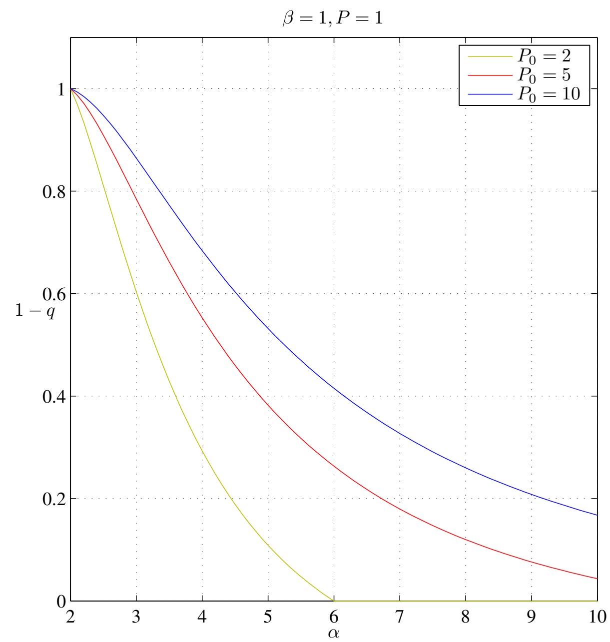

Fig. 2. The change of optimal switching off probabilities with respect to path loss in case of plane

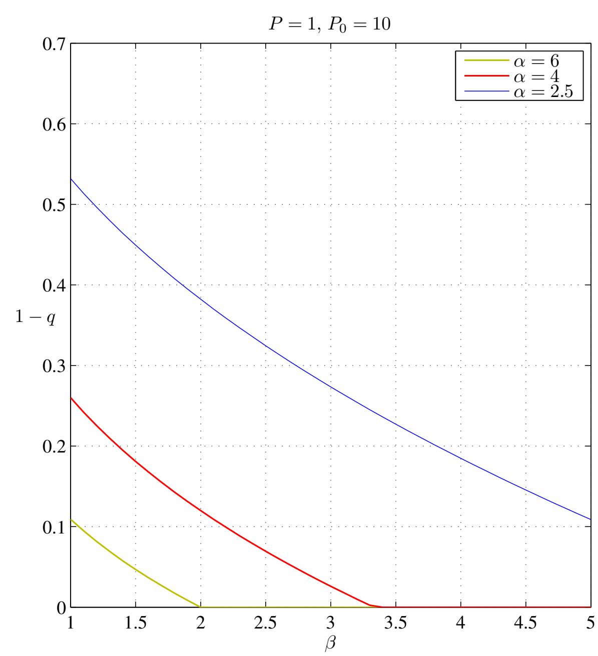

Fig. 3. The change of optimal switching off probabilities with respect to β in case of line

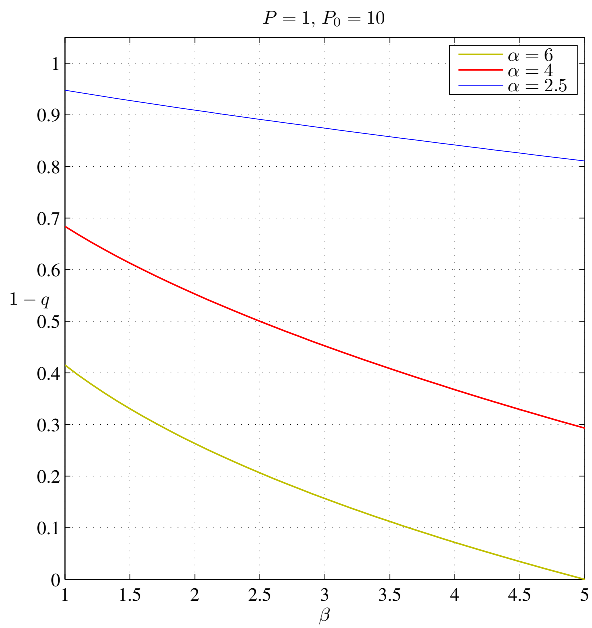

Fig. 4. The change of optimal switching off probabilities with respect to β in case of plane

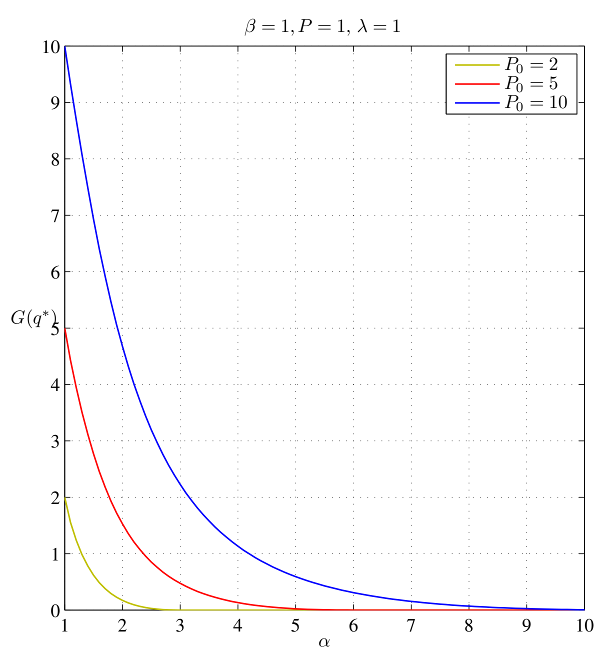

Fig. 5. The gain in power consumption with respect to path loss in case of line

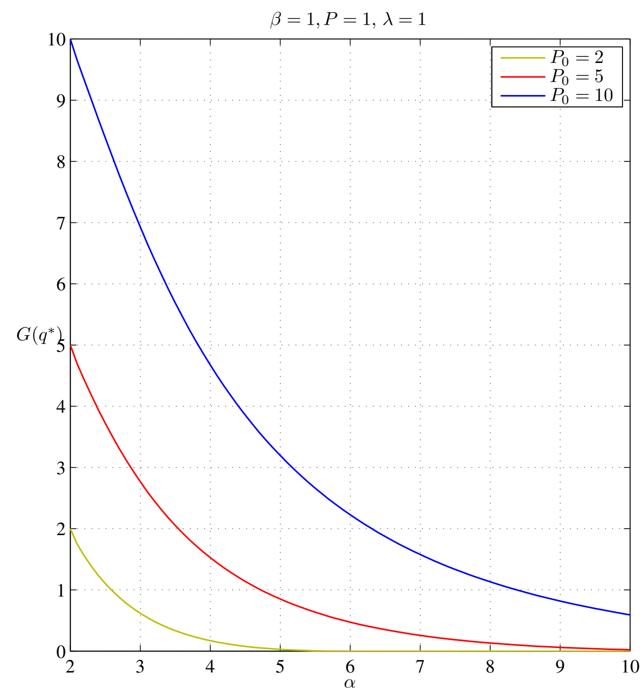

Fig. 6. The gain in power consumption with respect to path loss in case of plane